973334

Characterization of Belt Restraint Systems in Quasistatic Vehicle Rollover Tests

James F. Pywell
Delphi Automotive Systems

Stephen W. Rouhana and Joseph D. McCleary
General Motors Research and Development Center

Kenneth H. DeSaele
Modern Engineering

ABSTRACT:

In this study, we investigate a new method of testing the occupant kinematics in a rollover crash situation. Much of this work is based on previous full scale vehicle studies by Orlowski and Bahling (1,2). Their work concentrated on FMVSS 208 dolly rollover tests of vehicles equipped with production and reinforced vehicle roofs. They found that the occupant's kinematics, as opposed to roof crush, were responsible for potentially injurious neck injuries as a result of diving type accident kinematics of the head and torso.

This led us to examine seat system, belt restraint system and belt restraint anchorage designs that could potentially improve the occupants head to roof clearance.

A simulated vehicle environment with representative seat and belt restraint systems was chosen as the baseline system. These quasistatic tests applied a rigid roof / seat and belt restraint geometry. Kinematics of a 50th percentile Hybrid III dummy were analyzed in the quasistatic test procedure. Modifications of the seat, belt restraint system, and its anchorages changed the trajectory and kinematics of the dummy. This paper describes the laboratory test fixture, test method for simulating rollover, and results of some of over thirty rollover tests. Based on these results, a seat, belt restraint, and belt restraint anchorage design is described for this vehicle environment that reduced the excursion of the dummies from their seats in these simulations.

INTRODUCTION:

Rollover crashes and potential injury countermeasures are being examined more closely as improved vehicle countermeasures addressing other more predominant modes of crashes, such as frontal , side and rear have become more common. Rollover, by far, a much less frequent crash type (2.1% vs. 97.9% for all other crash modes) is yet considerably more harm-inducing when injuries and fatalities are measured against other crash types. (3.7% and 18% respectively) This suggests that high energy is involved in such a crash, and that a high percentage of injuries and fatalities are a result of unbelted occupants involved in the rollover crash. (3). Belted occupants in rollover crashes, although much less likely to be severely or fatally injured, can be injured because of the complexity of the rollover crash.

Regulatory agencies typically attempt to mitigate injury found in the motoring public by mandating an occupant protection performance requirement, which is typically confirmed with a specific test procedure.

In 1991, NHTSA issued docket 91-68, requesting comments on a proposal to specify a rollover test procedure, otherwise known as the T/2H method. This method was supposed to aid in the prediction of vehicle rollover propensity. Vehicle manufacturers responded by providing measurement and field data on vehicles which indicated that this test ratio lacked correlation to the real world.

As a result of these comments and data, regulatory action was stopped and the issue was sent to NHTSA R&D for additional study.

Recent public meetings with NHTSA indicate that rollover ejection mitigation remains one of the research projects NHTSA is funding.

Thus, rollover crashes are being studied but there are no regulatory test standards or regulated injury indices at this time.

NHTSA's data on rollover fatalities, compared to other fatal crash types (frontal, side, and rear) yields rollover fatalities rates in small, medium and large passenger cars between 15 and 24 percent, while for sport utilities, vans and pickups, it varies between 36 and 62 percent. The comparatively high fatality rate for rollover vs. other crash types suggests the disproportionately high degree of harm associated with rollovers. According to James' et al. (4) review of the 1988-94 NASS, although the number of occupants exposed to rear impacts is similar to those exposed to rollovers (8%), rear impacts contribute to only two percent of the Harm from motor vehicle collisions while rollovers contribute to a disproportionate 17 percent of the Harm.

Thus, rollover countermeasures may be an area with significant potential to help reduce injuries and to offer additional safety countermeasures for vehicle occupants.

UNBELTED OCCUPANTS IN ROLLOVERS:

Felrice [1992] estimated that rollover injuries could be reduced by 75% if occupants would use their belt restraints. This is particularly true in the U.S. and countries where low belt usage rates have been the norm. Today, ejection mitigation is being addressed by looking at improved glazing, improved door latches, and specialty sidebag, headbag and/or roof bags. These developments are aimed directly at the most serious injury mechanism that causes rollover injuries, viz., ejection.

Injury caused by occupant contact within the vehicle is being addressed by improved vehicle 'greenhouse' padding. Side, head and roof airbags may help to reduce injury from interior impacts.

Injury due to unrestrained occupant partial ejection or intruding surfaces impacting the occupant will remain difficult to address due to the randomness and severity of the rollover crash. Complications from the occupant being able to make contact nearly anywhere during the rollover crash prevents a prediction of where contact will occur for placement of a countermeasure.

BELTED OCCUPANTS IN ROLLOVERS:

In spite of the large number of unbelted occupants in rollovers, rollovers do occur with belted occupants and some of these are injured. In Europe, where a higher percentage of rollover cases have belted occupants, rollover crash injuries are still documented. In one German study by Zobel (5) where 99 belted-occupant rollover cases were examined, 72 percent of the involved persons had injuries, although none were above an AIS=3 injury. As a greater percentage of the U.S. driving population uses seatbelts, the belted rollover condition may become more prevalent.

The propensity for rollovers may increase as an accident mode as well. Evans (6), compared the ratio of the number of crashes under an adverse condition for vehicles with and without Antilock Braking System (ABS) and showed that ABS equipped vehicles had an increased rollover incidence (44 +/- 22%). He further cites a Transport Canada study by Smiley (7) that provides direct evidence that drivers of vehicles equipped with ABS choose higher travel speeds. Janssen (8), in an instrumented study, observed that a one percent increase in speed was associated with greater safety belt usage. These occupants presumably put their belts on to offset their higher driving speeds.

Between 1985 and 1995 the US went from 15% to 68% belt usage. Canada went to 87% in the same time period with laws mandating primary belt usage enforcement. States upgrading to primary enforcement have seen usage rates increase between 10 and 15 percent soon after the law was enacted. North Carolina's "Click It or Ticket" program has been cited as the stimulus for achieving an 85 percent usage rate (9). These statistics suggest that an effective rollover injury crash countermeasure might be primarily occupant restraint system based rather than vehicle interior based.

One might characterize this phenomenon graphically by plotting a trend line that shows a steady or increasing number of rollover crashes and an increasing trend for belted occupants. While it is unlikely that all unbelted rollovers will be eliminated, As the number of belted occupants increases, the potential benefit of a rollover countermeasure for belt restraint will also increase. (see Figure 1.)

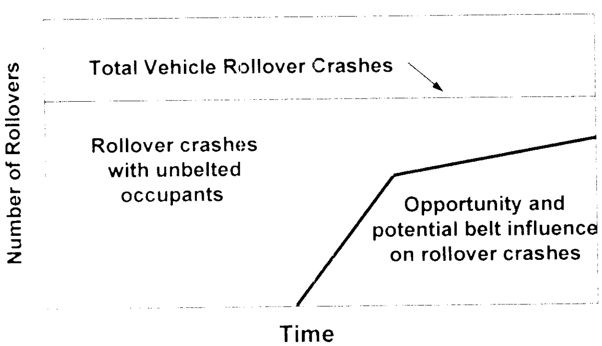


Figure 1, Belt usage trends in rollovers

BELTED ROLLOVER INJURY MECHANISMS:

In the belted rollover crash, rollover injuries to belted occupants are likely dependent upon many variables.

The interior space available to the occupant, due to either the vehicle geometry, pre-crash position of that occupant or occupant size may affect their outcome. The occupant restraint may also have an influence on the likelihood of interior contact.

Other factors such as the vehicle interior shape, and stiffness; the duration and quantity of occupant-to-interior strikes, and the relative impact velocity between the occupant and the striking surface may also contribute to the injury potential.

Additional vehicle occupants and cargo that are insufficiently restrained or unrestrained may also provide contact hazards. Finally, the interior integrity and geometry, coupled with occupant restraint performance may further determine the opportunity for partial or full ejection related injuries.

REVIEW OF PAST RESEARCH:

Many tests have been conducted to determine an occupant's rollover kinematics and the potential for injury. These involve full scale vehicle tests, quasistatic tests and modeling efforts.

FULL SCALE TESTS:

The Malibu II series, a series of full scale FMVSS 208 vehicle rollover tests by Bahling et al. in the late 1980's examined belted restraint performance with both reinforced and non-reinforced roofs in mid-size four door sedans. Potentially injurious incidents (PII) occurred in both test conditions, but were more prevalent in production roof vehicles. This was attributed to the fact that the production vehicles had 53 percent more roof rail to ground impacts than did the rollcage equipped vehicles. This greater frequency of impacts provided a greater opportunity for PII. The reduction or elimination of roof deformation had no effect in reducing neck loads for the dummy when the vehicles experienced a roof-to-ground contact. This was explained further by the fact that the dummy's head was able to contact the roof panel because of centrifugal forces and sufficient slack in the belt restraint.

Freidewahl (10), performed FMVSS 208 dolly testing on small two door coupes with belted dummies. Freidewahl's primary focus was on studying contact forces and the resultant vehicle body roof deformations. He found that absolute roof deformations were not an acceptable rating of vehicle body structural performance, again, primarily due to the randomness of the vehicle body's rollover kinematics. The dummy kinematics were analogous to the Malibu dummy kinematics. Centrifugal force pulled the dummy to the roof header. The author does not discuss neck compression measurements, but notes that the "biomechanic measurements during the laboratory crashes suggest no danger for the occupants."

Twelve ramp / screw type vehicle rollover tests by Sakarai et al (11) also resulted in restrained dummies being forced to the roof header by centrifugal forces, even though the method of rolling the vehicle was altered. Axial neck compression was a suspected mode of injury, as the dummy's head was loaded by the torso. In each of these tests, even though the emergency locking retractor (ELR) was locked and prevented additional excursion, the belt restraint still had sufficient slack to allow the dummy's head to reach the roof header.

In each of these full scale vehicle rollover crash series, investigators asserted that a primary injury mechanism could be the inertia of the dummy torso compressing the neck axially after the head was stopped by impact with the vehicle interior.

QUASISTATIC TESTS:

Another test type is the quasistatic rollover test. This type of testing is a simplification of the full scale test but is more repeatable and easier to control.

Herbst et al. (12) placed 5th, 50th and 95th percentile human volunteers in a seat on a spit fixture with its axis of rotation in an antero-posterior direction through the occupant's torso in a mid-sagittal plane. The belt restrained volunteers were then inverted and vertical head excursion was measured by reference video cameras. A single seat and three types of belt restraint systems representing three different vehicle configurations were tested. This meant a generic belt geometry was applied meeting a recommended practice citec in an SAE Vehicle Occupant Restraint Systems and Components Standards manual. This geometry was not representative nor optimized for a specific production vehicle. Tests were conducted both statically and then dynamically with an approximate 100 degree / second average rotation velocity. Seat longitudinal location was moved fore to aft for the 5th through 95th percentile volunteers respectively. The effects of modifications to the belt anchorage locations were examined by making the lap belt anchors totally symmetric around the seat with lower vertical anchor points and minimal lateral spacing. This resulted in less vertical head target excursion. Occupant torso lengthening, (due to a straightening of the occupant's spine) was observed in the 95th percentile volunteer, adding as much as 60mm to the volunteer's absolute vertical head excursion. Part of the added head vertical displacement may have been a result of the shoulder belt being unable to provide sufficient retention of this occupant to the seat back.

A test series performed by Arndt et al. (13) also involved inverting volunteer subjects of 5th, 50th and 95th percentile statures and a 95th percentile Hybrid III. The human tests were quasistatic, while the dummy tests were dynamic and involved exposing the Hybrid III to a purely vertical -5Gz pulse. Rigid seats were used and the single loop lap belt restraint systems used were unrepresentative of production belts and possibly not with regulatory anchorage zones. The belt restraint was modified to have different degrees of tension ranging from 50mm slack (i.e. no pretension) to no slack and 222N pretension. Belt anchorage angles were 37 and 70 degrees relative to horizontal when fitted to the 95th Hybrid III. Depending upon stature and belt tension, statically inverted head displacement varied from approximately 30mm to 140mm with the very upright lap belt angle, and approximately 65mm to 175mm with the more shallow lap belt angle. Dynamically, the 95th Hybrid III exhibited between approximately 195mm to 285mm head excursion in these same restraint system conditions.

In another test series, Arndt et al. (17) conducted tests to determine how much belt restraint length would need to be removed to hold a mannequin vertically stationary in a vehicle seat and belt restraint system during rollover. Instead of performing an inverted roll test, the authors' test procedure involved lifting a belted mannequin in two different types of vehicle seating arrangements in a vehicle and determining the X,Y,Z displacement as a function of belt restraint characteristics. The mannequin was a rigid torso / pelvis / stub leg replica of a 50th percentile Hybrid III with an un-specified mass. An 890N lifting force applied to the mannequin resulted in different lift heights. Modifying the single loop belt restraint length, by removing between 206 and 244mm of belt restraint length, reduced the vertical height displacement of the mannequin to zero.

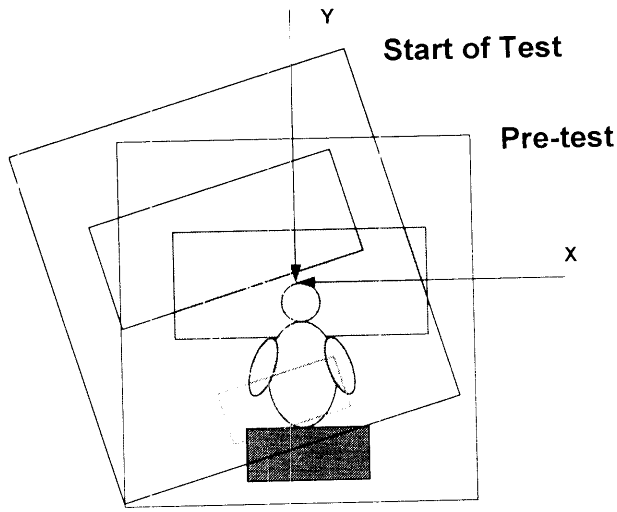


Figure 3: ATD Positioning

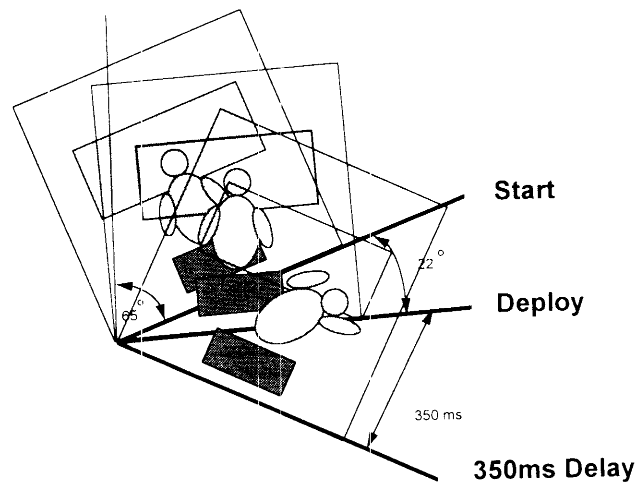


Figure 4: Rollover Cage Kinematics

In both of Arndt's tests, the conclusion was that a shorter, more vertical lap restraint design would be beneficial to reducing vertical head excursion in rollover.

Each of these aforementioned authors relate the potential injury to occupant excursion.

METHODS:

The aim of the present study was to characterize belt restraints in another quasistatic test method. It is recognized that the fixture cannot truly duplicate the FMVSS 208 dolly rollover test, but may provide insight into occupant kinematics during rollovers. Most actual vehicle rollovers involve a tripping mechanism that imparts lateral forces. This test does not represent that condition.

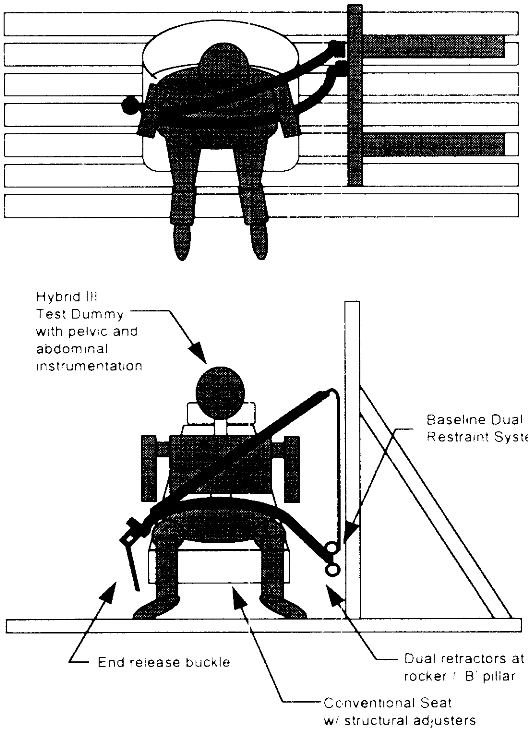


FIGURE 5: BASELINE DUAL RETRACTOR, STITCHED LATCH PLATE RESTRAINT SYSTEM

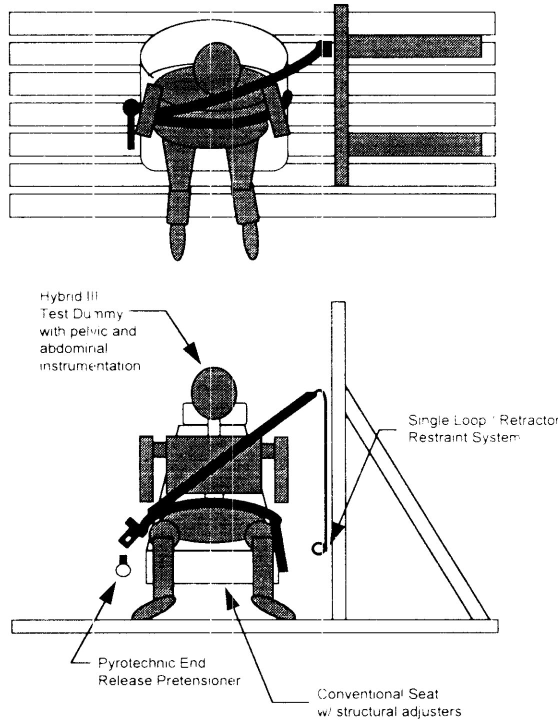


FIGURE 6: SINGLE LOOP RESTRAINT W/ FREE SLIDING LATCH PLATE & PRETENSIONER

The average first roll rate of the Malibu II series was approximately 360 degrees per second with one peak rotational velocity measured at 450 degrees / second. Our quasistatic fixture could achieve a peak rotational velocity of approximately 240 degrees per second with an average rotational velocity of 140 degrees / second between horizontal and 90 degrees of rotation. This was accomplished by starting the rotation of the fixture from 25 degrees above horizontal. Actual vehicle rollovers sometimes involve multiple rolls with considerable lateral displacement of the vehicle. This procedure involved a 290 degree rotation around a stationary axis with several backswings damping to zero.

Ground contact effects seen in full scale tests, being random and unpredictable, were not simulated in this quasistatic fixture test procedure.

This test attempts to replicate the occupant's potential trajectory and displacements on a driver side leading roll, simulating a road shoulder step-off type roll event. The effects on occupant kinematics , by modifying the vehicle seat, belt restraint system and belt geometry, were monitored.

A quasistatic test procedure that emulates critical dummy kinematics, and is controlable, repeatable and was easily and quickly modifiable could have significant benefits compared to full scale testing.

The benefits of this type of test are numerous. Costs involved with running a FMVSS 208 dolly rollover tests are large. Vehicles are not always available for testing, e.g. an advanced vehicle prototype.

Another benefit is clear frontal, side and plan views of the dummy and its kinematics for film coverage. Additionally, one can modify and expand the belt geometry anchorage options with a generic test fixture.

Data collected in this quasistatic test series includes: high speed film and video of both side and frontal views, belt loads, dummy pelvic loads and dummy head, chest and pelvic accelerations.

The fixture consists of two 2.5 m tri-mount stanchions, a 3.25 m axle straddling the stanchions, and a rectangular cage that housed the simulated vehicle environment. Stanchions were constructed from 250mm x 160mm webbed 'I' beams, mounted to a structural 'T' bed plate reinforced in the concrete flooring. The axle was a 25mm thick wall, 150mm diameter hollow tube that provided a conduit for cables to the dummy and recording equipment aboard the fixture. The 3.25 m long x 2.0m wide by 1.75m high cage was constructed from a combination of 50 and 100 mm square tubing, with one long corner constructed and joined about the axle which is fixed to and rolls with the cage. Front, right and left camera stanchions were mounted for video and film cameras.

The dummy was positioned nominally the same prior to each test so that the forehead target was aligned vertically with a target located on the displacement board behind it. See Figure (3)

The fixture was rotated up to the 25 degree starting rotation and released, propelled by gravity. As the fixture was being rotated to the starting point, the dummy in the conventional seat / restraint tests typically leaned inboard between 50 and 70 mm. This distance is reported as part of the lateral displacement data.

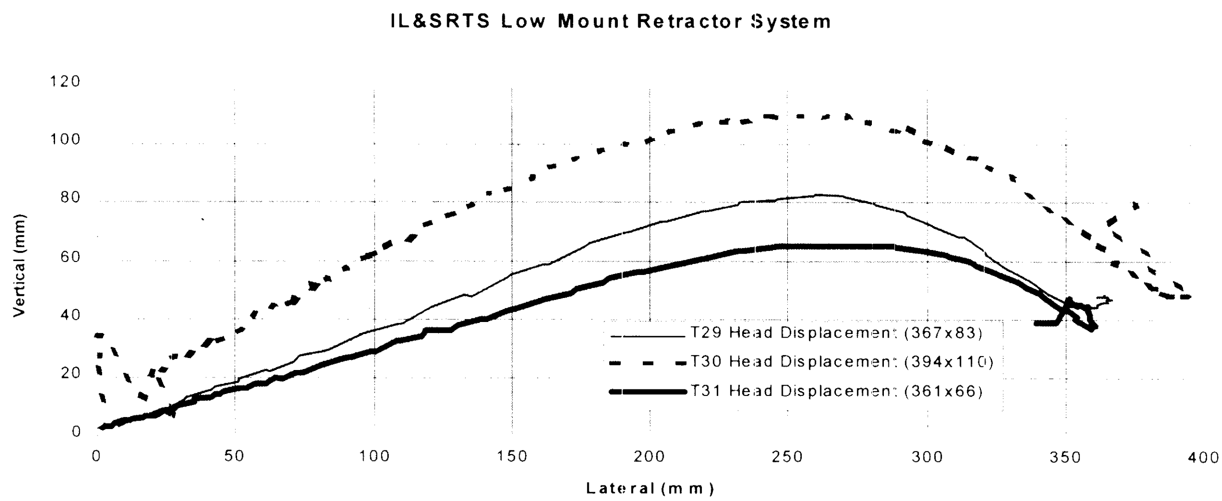


Figure 12: IL&SRTS Low Mount Retractor: (z:86 - y:374)

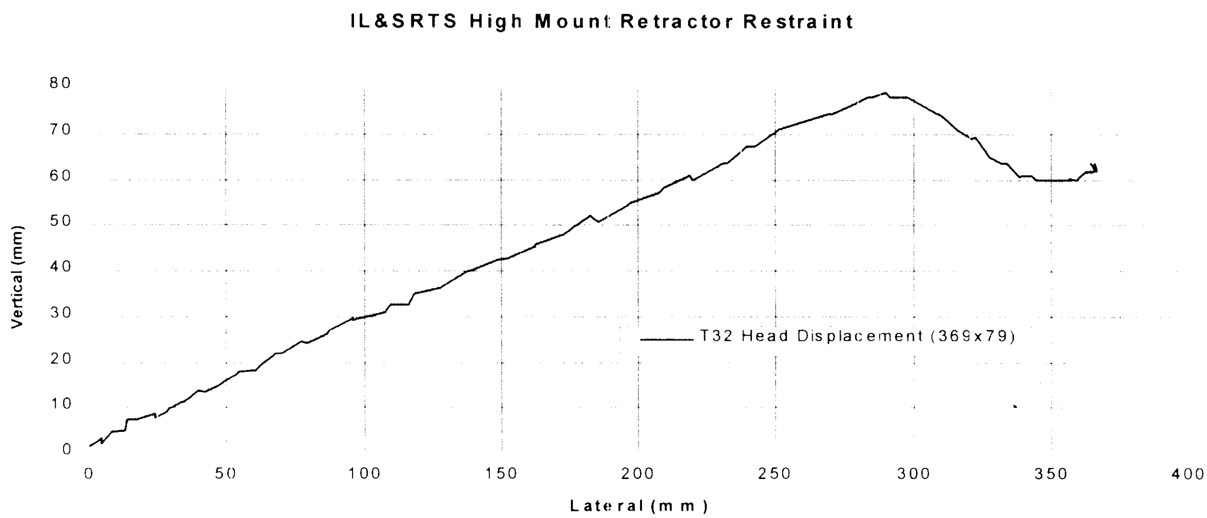


Figure 13: IL&SRTS High Mount Retractor: (z:79- y:379)

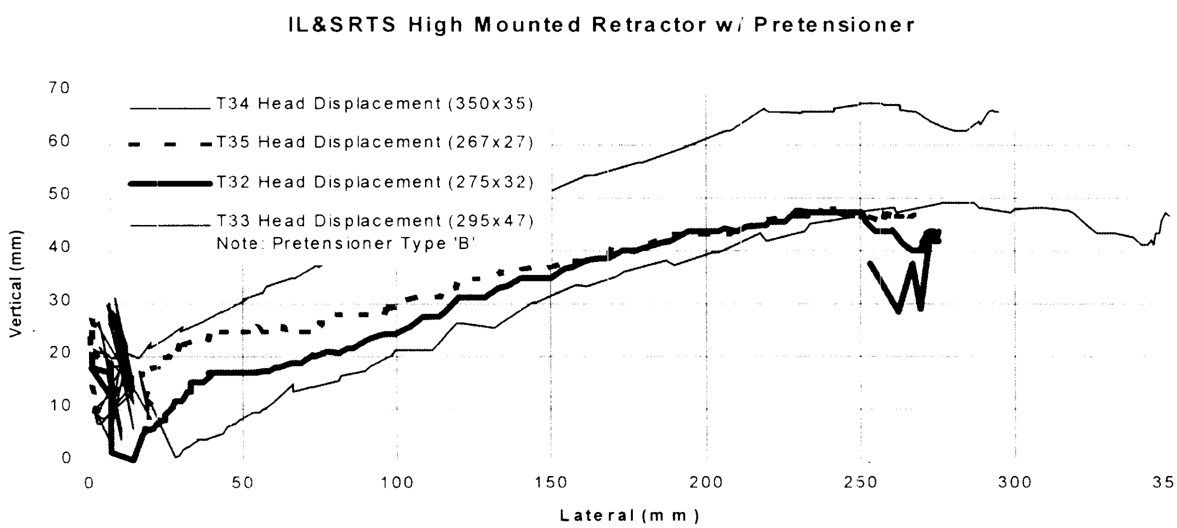


Figure 14: IL&SRTS High Mount Retractor w/Pretensioner: (z:36- y:297)

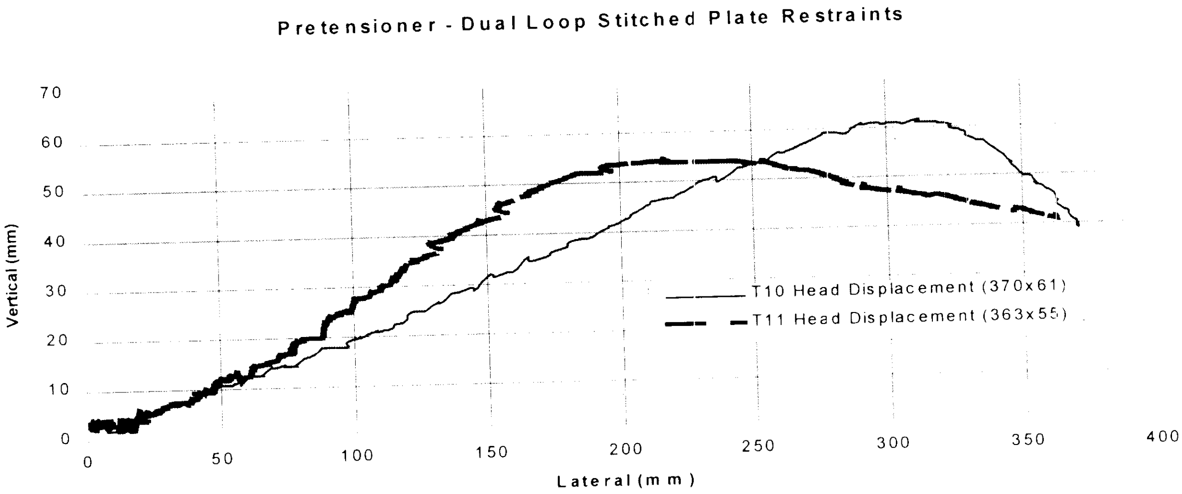


Figure 9: Dual Retractor, Stitched Latch Plate w/Pretensioner (z:58 - y:367)

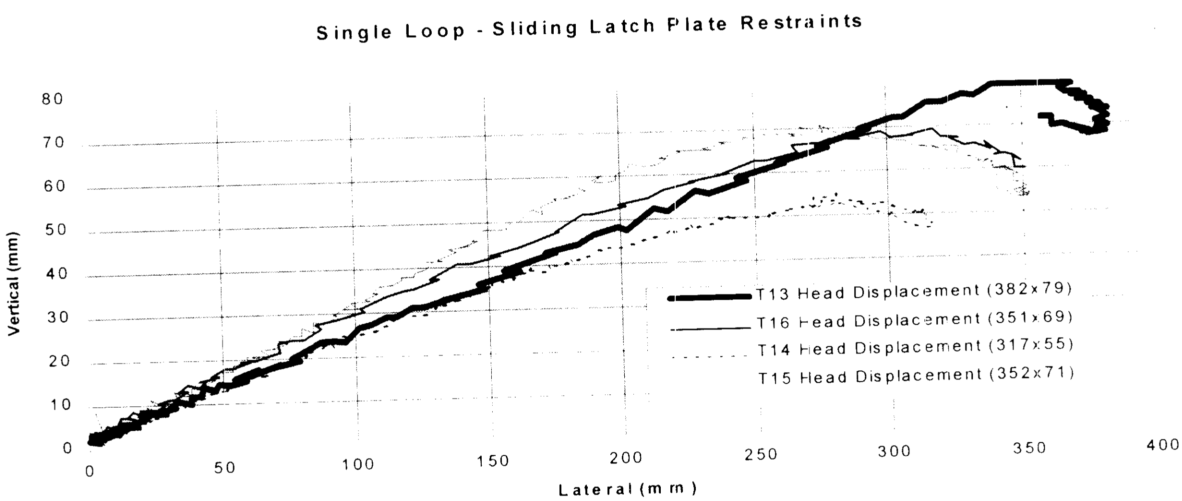


Figure 10: Single Loop: (z:69 - y:351)

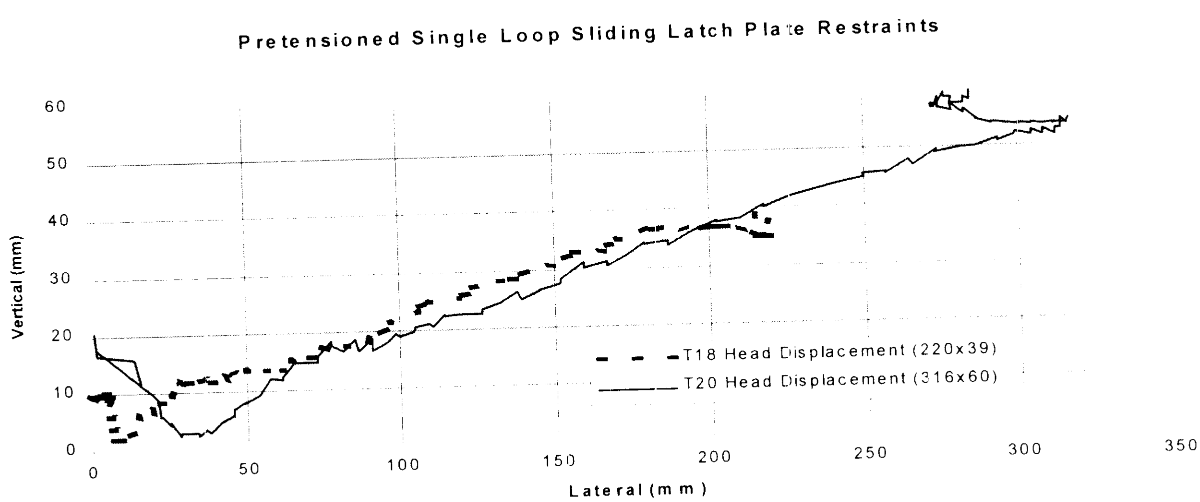


Figure 11: Single Loop w/ Pretensioner: (z:49 - y:269)

Belt Restraint Type / Condition	Average Vertical Excursion (mm)	Delta to Baseline	Percent Reduction vs. Baseline	Average Lateral Excursion (mm)	Delta to Base line	Percent Reduction vs. Baseline
No Restraint	295			444		
Baseline Dual Loop w/ Stitched Latch Plate	98	0	0	432	0	0
Dual Loop w/ Stitched Latch Plate, Pretensioner	58	40	41	367	65	15
Single Loop Restraint	69	29	30	351	81	19
Single Loop Restraint, Pretensioner Buckle	49	49	50	269	163	38
IL&SRTS - Low Retractor	86	12	12	374	58	13
IL&SRTS - High Retractor	79	19	19	370	62	14
IL&SRTS - High Retractor, Pretensioner Buckle	36	62	63	297	135	31

Table 3: ATD Head Target Excursion

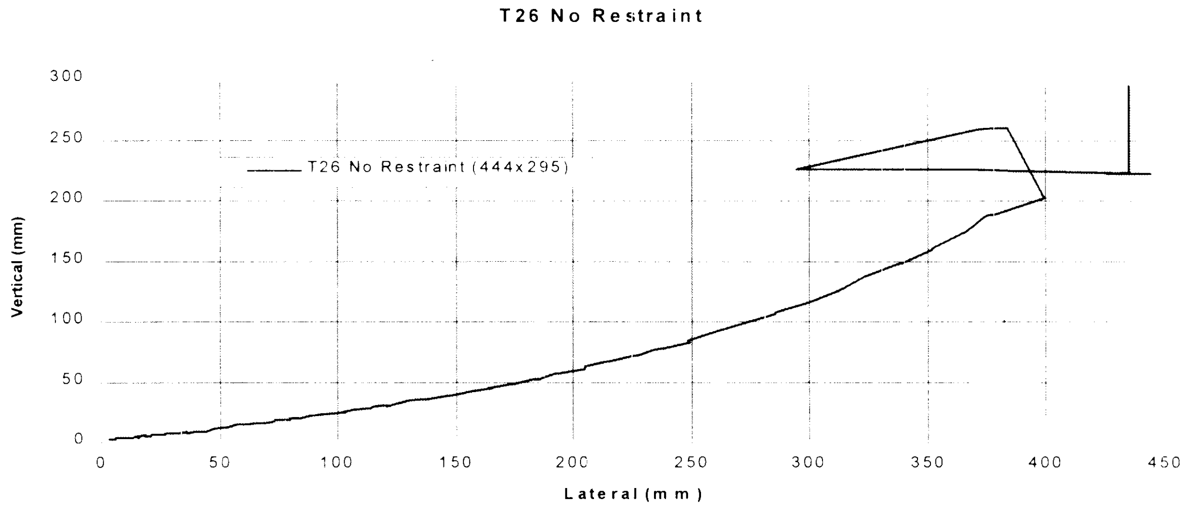


Figure 7: ATD Head Target - No Restraint: (z:295 - y:444)

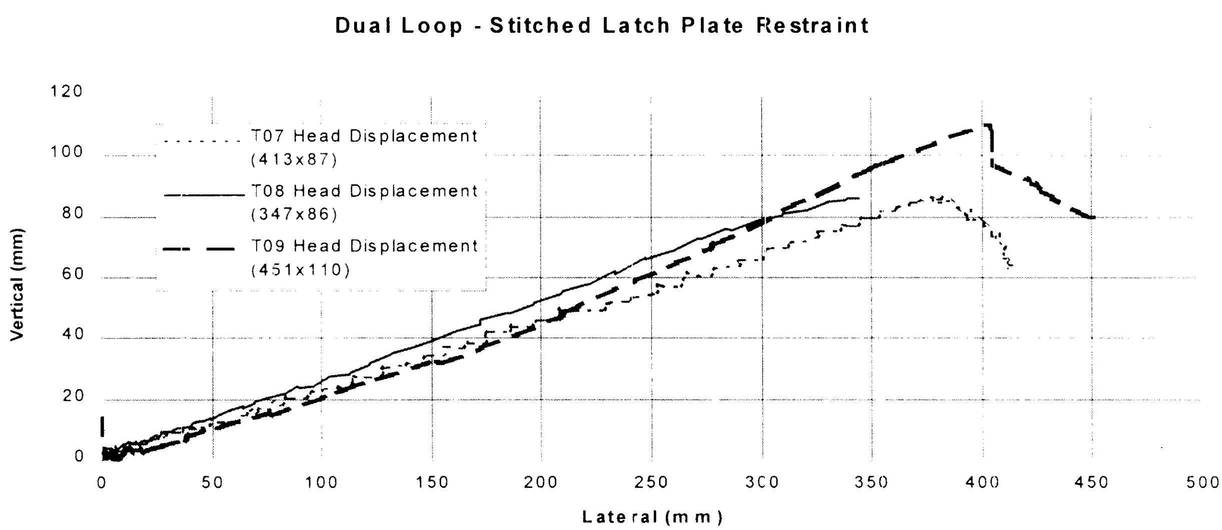


Figure 8: Dual Retractor, Stitched Latch Plate (z:98 - y:432)

Test Number	Test Condition	Upper Neck Load FX + N	FX - N	FY + N	FY - N	FZ + N	FZ- N	MX Nm	MY Nm	MZ Nm	Thorax Vert Acc g	Pelvis Res Acc g	Lumbar Load FX + N	FX- N	FZ+ N	FZ- N	MY N-m	Belt Loads Inbd Lap N	Shoulder N
5	DL, FLP	854	-280	17	-122		-191	-5.1	4.8	3.7	3.48	5.18	0	-813	4.5	-540	-87.8	ND	ND
7	DL, FLP	793	-344	16	-116	5	-183	-4.4	5.2	-2.6	3.22	6.46	27	-988	0	-765	-53.4	973	221
8	DL, FLP	544	-340	19	-135	0	-190	-6.4	6.7	-4.2	3.45	3.33	13	-891	22	-723	-48.6	980	262
9	PT/DL, FLP	624	-624	14	-154	0	-194	-7	8.6	-4	3.97	3.23	0	-996	24	-838	-35	1055	374
10	PT/DL, FLP	542	-141	16	-126	9	-222	-4.1	3.3	-3.5	3.6	4.02	44	-941	10	-763	-58.7	958	250
11	PT/DL, FLP	712	-118	21	-116	0	-229	-3.7	3.1	-1.4	3.26	ND	ND	ND	ND	ND	ND	640	230
12	Prefired PT	ND	ND	14	-128	12	-194	-5.6	5	-5.4	3.4	4.04	21	-941	49	-661	-61	882	327
13	SL, SLP	254	-398	11	-144	13	-164	-5	4.8	-2.5	3.15	3.35	2	-605	34	-547	-41.3	874	312
14	SL, SLP	302	-378	16	-145	14	-161	-5.1	5.2	-1.5	3.05	2.67	30	-538	29	-543	-35.2	774	396
15	SL, SLP	564	-318	18	-180	13	-220	-7.7	5.7	-4.4	3.36	2.49	29	-499	5	-525	-39.2	747	496
16	SL, SLP	281	-103	16	-170	8	-211	-6.7	3.9	-1.7	3.16	3.78	49	-592	40	-540	-45.5	889	691
18	PT/SL, SLP	336	-307	24	-123	18	-152	-4.4	4.2	-4.1	2.86	3.45	76	-721	9	-413	-47.1	729	630
19	PT/SL, SLP	280	-293	16	-147	3	-169	-5.3	5.1	-4.6	3.26	3.38	0	-657	13	-501	-42.8	836	178
20	PT/SL, SLP	178	-314	14	-135	3	-161	-4.6	3.9	-4.1	2.84	2.76	69	-612	2	-424	-47.5	678	496
26	NR	3743	-160	252	-123	2207	-244	11.2	105	ND	7.63	7.33	1149	-36	527	-804	-87.6	0	0
27	NR	3797	-217	239	-112	2277	-274	-8.9	108	ND	3.62	7.68	940	-104	241	-918	-61.1	0	0
28	NR	3165	-106	202	139	2494	-179	18.6	94	-93.7	3.84							0	0
29	IL&SRTS, LM	490	-309	17	-138	4	-178	-4.5	5.9	-8	3.23	2.99	22	-509	20	-569	-23.6	693	380
30	IL&SRTS, LM	395	-151	20	-159	7	-190	-5.8	5	-8.7	3.44	2.98	31	-634	13	-696	-29.1	813	443
31	IL&SRTS, LM	616	-244	18	-139	7	-180	-5.1	6.1	ND	3.16	3.36	15	-536	4	-629	-44.3	786	423
32	IL&SRTS, HM	340	-378	16	-137	10	-183	-5	6	-14.9	3.25	2.72	16	-656	41	-736	-7.9	710	328
33	PT/IL&SRTS, HM	367	-169	17	-112	4	-170	3.9	3.9	ND	3.08	1.48	83	-552	8	-550	-27.5	645	410
34	PT/IL&SRTS, HM	256	-268	17	-130	17	-166	4	4.5	-2.5	3.13	2.68	103	-735	19	-571	-37.6	680	242
35	PT/IL&SRTS, HM	297	-261	17	-113	4	-167	3.6	4.3	-2.5	3.04	1.76	96	-671	87	-476	-43.6	675	273
36	PT/IL&SRTS, HM	297	-253	15	-128	9	-164	4.1	4.2	-2.7	3.06	3.13	136	-627	32	-411	-44.2	668	332

KEY	
DL, FLP	= Dual Loop Restraint w/ Fixed (Stitched) Latch Plate
PT/DL, FLP	= Pretensioned system above
SL, SLP	= Single Loop, Sliding Latch Plate
PT/SL, SLP	= Pretensioned system above
NR	= No Restraint
IL&SRTS, LM	= Integrated Lap & Shoulder Restraint to Seat, Low Mounted Retractor
IL&SRTS, HM	= Integrated Lap & Shoulder Restraint to Seat, High Mounted Retractor
PT/IL&SRTS, HM	= Pretensioned system above

Table 1: ATD Data

Number of Tests Averaged	Test Condition	Peak Pelvis Load Bolt Force/Time Lower Left N	Mid Left N	Upper Left N	Lower Right N	Mid Right N	Upper Right N	Upper Neck Load FX + N	FX - N	MX Nm	MY Nm	MZ Nm	Thorax Vert Acc g	Pelvis Res Acc g	Lumbar Load FX + N	FX- N	FZ+ N	FZ- N	MY N-m	Belt Loads Otbd Lap N	Shoulder N
3	DL, FLP	-28	-33	0	-58	-6	-14	730	-321	-5	6	-1	3	5	13	-897	9	-676	-63	977	242
3	PT/DL, FLP	-41	-16	0	-43	0	-13	626	-294	-5	5	-3	4	4	22	-969	17	-801	-47	884	285
4	SL, SLP	-16	-27	0	-35	-6	-13	350	-299	-6	5	-3	3	3	28	-559	27	-539	-40	821	474
3	PT/SL, SLP	-17	-18	0	-30	-7	0	265	305	-5	4	-4	3	3	48	-663	8	-446	-46	748	435
3	NR	0	0	0	0	0	0	3568	-161	7	102	-94	5	8	1045	-70	384	-861	-74	0	0
4	IL&SRTS, LM	-22	-12	0	-27	-10	-13	500	-235	-5	6	-8	3	3	23	-560	12	-631	-32	764	415
1	IL&SRTS, HM							340	-378	-5	6	-14.9	3.25	2.72	16	-656	41	-736	-7.9	710	328
4	PT/IL&SRTS, HM	-6	-23	0	-27	-6	-16	304	-238	4	4	-3	3	2	105	-646	37	-502	-38	667	314

KEY	
DL, FLP	= Dual Loop Restraint w/ Fixed (Stitched) Latch Plate
PT/DL, FLP	= Pretensioned system above
SL, SLP	= Single Loop, Sliding Latch Plate
PT/SL, SLP	= Pretensioned system above
NR	= No Restraint
IL&SRTS, LM	= Integrated Lap & Shoulder Restraint to Seat, Low Mounted Retractor
IL&SRTS, HM	= Integrated Lap & Shoulder Restraint to Seat, High Mounted Retractor
PT/IL&SRTS, HM	= Pretensioned system above

Table 2: Average ATD / Belt Loads

CONCLUSION:

Various approaches utilizing the seat belt and seat have been shown to reduce dummy excursions in simulated rollovers. Belt geometry, belt hardware configurations and belt tensioning were the parameters with the greatest effect on dummy kinematics.

ACKNOWLEDGMENT:

The authors acknowledge the efforts of GJ Keller in these tests.

REFERENCES:

1) Orlowski, K, Bundorf, RT; Moffat, EA. Rollover Crash Tests - The Influence of Roof Strength on Injury Mechanics. SAE 851734 29th Stapp Conference. Nov 1985.

2) Bahling, GS; Bundorf, RT; Kaspzyk, GS; Rollover and Drop Tests - The Influence of Roof Strength on Injury Mechanics Using Belted Dummies. SAE 902314. 34th Stapp Conference. Nov 1990.

3) National Highway Traffic Safety Administration, U.S. D.O.T. B.T. S. CD-10. Traffic Safety Facts 1994: A Compilation of Motor Vehicle Crash Data From the Fatal Reporting System and the General Estimates Systems.

4) James, MB; Allsop, DL; Nordhagen, RP; Decker, RL; Injury Mechanisms and Field Accident Data Analysis in Rollover Accidents; SAE 970396. SAE Congress. Feb 1997.

5) Zobel, R. Analysis of Actual Vehicle Rollovers. Data from "Collision Research and Road Safety." Technical Institute Essen, Germany. Nov 1995.

6) Evans, L: ABS and Relative Crash Risk Under Different Roadway, Weather and Other Conditions. SAE 950353. Accident Reconstruction: Technology and Animation V (SP-1083) SAE Congress. Feb 1995.

7) Smiley, A; Rochford, S. Behavioral Adaptation and Anti-Lock Brake Systems. Report for Transport Canada. Oct. 1991.

8) Janssen, W; Seat-Belt Wearing and Driver Behavior: An Instrumented-Vehicle Study. Accident Analysis and Prevention 26:249-261; 1994.

9) Motor Vehicle Safety in the National Highway Designation Act of 1995. Library of Congress. Congressional Research Service. Oct 1995.

10) Friedewald, K: An Analysis of Body Loads During Rollover Tests, Roof Crush and Occupant Protection; Paper 96-S5-O-09; 15th ESV Conference. May 1996.

11) Sakarai, T.; Takigawa, Y.; Ikeno, H.; Study on Passenger Car Rollover Simulation. Paper S6-O-10. 13th ESV Conference. Nov 1991.

12) Herbst, B; Forrest, S; Wang, P; Chng, D; Friedman, D; Friedman K; The Ability of 3 Point Safety Belts to Restrain Occupants in Rollover Crashes. Paper 96-S5-O-12. 15th ESV Conference. May 1996.

13) Arndt, MW; Mowry, GA; Dickerson, CP; Arndt, SM; Evaluation of Experimental Restraints in Rollover Conditions. SAE 952712. 39th Stapp Conference. Nov 1995.

14) Arndt, MW; Mowry, GA; Baray, PE; Clark, DA. The Development of a Method for Determining Effective Slack in Motor Vehicle Restraint Systems for Rollover Protection. SAE 970781. SAE Congress. Feb 1997.

with a stitched latch plate and an end release buckle. This restraint was similar to the baseline conventional seat condition except that it was integrated to the seat system. It reduced vertical head displacement compared to the conventional seat baseline system by 12 percent while simultaneously reducing lateral head displacement by 13 percent. Again, the dummies rolled inboard further in the IL&SRTS compared to tests in conventional seats during the 25 degree above horizontal cage positioning prior to test. It would be expected that the lateral excursions of the dummy in the IL&SRTS systems would have been much less than those in a conventional system, particularly without a headrest belt guide loop because the effective shoulder anchor was closer to the dummy's shoulder. However, testing occurred at midpoint positions where the conventional seat's belt geometry was similar to the IL&SRTS design. Had testing been performed at the seats' extreme longitudinal positions, the conventional seat restraint system may have allowed even greater lateral excursion.

Figure 13 shows the data for a high mount IL&SRTS system. This system differed only in that the shoulder retractor was mounted high on the seat back, shortening the shoulder belt webbing length to the dummy. The data appears similar to the low mount shoulder retractor IL&SRTS system.

Adding a buckle pretensioner to the high mounted shoulder retractor IL&SRTS system resulted in reductions to vertical and lateral head displacements (63 and 31 percent, respectively) compared to the baseline conventional seat restraint system. (Figure 14.)

The effect of the pretensioner is as pronounced in the IL&SRTS data as in the conventional seat single loop restraint data. A rapid decrease in vertical head displacement is noted within the first 30mm of lateral displacement,. The majority of head vertical displacement during this period appears to be dummy head nod as compared to actual torso vertical displacement, drawing the head down with it. As the pretensioner tightens the shoulder belt rapidly against the dummy, the inertia of the head mass results in the head lagging and therefore, the head nods forward, drawing the head target down momentarily.

Table 2 gives the averages of multiple tests shown in Table 1. Pretensioned systems were associated with reduced belt loads, neck moments and longitudinal loads by approximately 10 percent in all tests with only one exception (Shoulder loop load +10% on Single Loop restraint system) in these tests. Pretensioning reduced vertical dummy head excursion in all restraint types between 41 and 63 percent while reducing lateral dummy head excursion in all restraint types between 15 and 38 percent.

The data shown in Table 3 summarizes the average head displacement data from the displacement plots. One key performance differentiator appears to be the single loop restraint system improvement of belt routing and resultant reduction in webbing payout and webbing elongation from only a single spool. Pretensioning further aided in retaining the dummy in all seat / restraint system combinations.

DISCUSSION:

Test results conducted per this Quasistatic Test Procedure provide the following insights:

• Single Loop Restraints with Sliding Latching Plates provided 30 percent less vertical and 19 percent less lateral head target excursion compared to dual loop stitched latch plate restraints. This may be attributed to:

1) improved belt geometry about the occupant as a result of migrating the outboard anchor onto the outboard structural seat adjuster;

2) reduced anchorage compliance as a result of a degree of web pay-out before the ELR functioned and eliminating spooled webbing elongation, and

3) the ability of the belt restraint to share loading between the shoulder and lap loop as a result of web migration in the free sliding latch plate, demonstrated in the approximately doubled shoulder belt loop load averages compared to the dual stitched latch plate shoulder loop load averages.

• IL&SRTS, with either high or low mounted retractor systems, appeared to provide similar dummy retention capabilities.

• In these tests and conditions, a single loop free sliding latch plate restraint applied to conventional seating better restrained the dummy (69z, 351y) when compared to the IL&SRTS restraint system (86z, 374y). Thus, a single loop restraint applied in the IL&SRTS designs may provide superior rollover dummy retention versus dual loop, stitched latch plate systems.

• The conventional seat's ability to restrain the dummy in other seating locations other than that tested using this procedure may not perform as well due to belt geometry changes. However, The conventional seat with a single loop restraint system might continue to provide similar rollover restraint in other positions if a headrest guideloop were applied. This is because the guideloop may preserve a more optimal belt routing in other seat longitudinal positions.

• The use of belt comfort features that allowed a degree of slack for occupant comfort might be offset by the application of a pretensioner triggered in a rollover crash.

• A belt restraint system that could draw the occupant down and back into the seat, while tightening the belt restraint sufficiently to minimize or eliminate torso excursion in all planes might reduce occupant contacts to interior and exterior surfaces. A device that could perform this task quickly enough to affect this positioning transformation, yet without inducing or exacerbating injury may further reduce occupant injury potential in rollover crashes.

• The test condition reported here represents an attempt to simulate in the laboratory, with a simple repeatable test, a portion of the dynamics found in the infinitely variable conditions that occur in rollover crashes seen in the field. While the authors believe this test to be adequate to elucidate trends in the data, the effects of confounding factors that occur in the field, such as lateral acceleration and multiple rolls, were not duplicated in the rollover fixture and test methodology used in this study.

• Other crash configurations not considered here (e.g. frontal impact and side impact) are far more frequent than rollovers. Additional development is necessary to study the effects of the belt restraint modifications discussed in this paper in crash configurations other than rollovers. Further optimization for differences in the size of the vehicle and for a range of occupant sizes would be necessary before production implementation of such restraint systems.

film spooling of the belt, allowing between 18 to 35 mm of displacement of a line drawn across the belt at the retractor. Therefore, each retractor was locked out in test data reported here.

SEAT AND BELT RESTRAINT CONFIGURATIONS:

Baseline conditions consisted of a rocker and 'B' pillar mounted dual retractor, dual loop restraint system with a stitched latch plate. An end release buckle was attached to the inboard structural seat adjuster. (Figure 5) Modifications to this system began by:

(1) Applying an end release buckle pretensioner to the baseline system. The pretensioner stroke varied between 42 and 57mm, and was initiated when the fixture rotated 22 degrees from its starting point. The 22 degree rotation was selected from a known vehicle rollover sensing algorithm.

(2) Migrating the outboard lap anchor from the rocker mounted retractor to a fixed anchor symmetrically mounted to the outboard seat adjuster. A single loop shoulder retractor, with a free sliding latch plate and an end release buckle was also used. (Figure 6)

(3) An end release buckle pretensioner was then tested with the sliding latch plate single loop restraint. The pretensioner strokes varied between 39 and 57mm in these tests. The pretensioners were initiated 22 degrees past the starting point. (see Figures 4-6)

Tests were also conducted on IL&SRTS systems that used two different restraint types.

(4) The first IL&SRTS contained a dual loop, dual retractor stitched latch plate, with an end release buckle, the same restraint condition described in the conventional seat baseline tests. The shoulder belt retractor was mounted at the base of the seatback, with the shoulder belt routed up the seat back and exiting at an effective shoulder anchor point at the top of the seat back.

(5) The second seat contained a dual loop, dual retractor stitched latch plate, with an end release buckle and a high mounted shoulder retractor supplying a direct feed from the shoulder retractor to the occupant.

6) Only the high mount IL&SRTS was modified. The modification was the addition of an end release buckle pretensioner.

Again, in these tests, the ELR was locked out prior to testing. The belt restraints were production restraint systems applying a seven panel, eight percent elongation webbing, with an average single loop length of 2.27 meters in the conventional seat tests. Belt elongation was not measured.

The seats were leather trimmed with structural seat adjusters capable of restraining lap anchor loads required of FMVSS 210. The 'H' points of both seat types, measured according to SAE J826, revealed an average 'D' point dimension of 42mm and 37mm for the conventional seats and IL&SRTS respectively. (The 'D' point is the corresponding maximum displacement point of the two dimensional SAE J1100 template based on SAE J826 3D 'H' point machine empirical results.) There is no correlation of Hybrid III positioning and SAE J826, therefore, an equivalent 'D' point positioning of the Hybrid III could only be estimated as being similar to the SAE J826 results.

Quasistatic rollover tests were performed on the belt restraint systems described earlier to determine vertical and lateral head excursion of each restraint type. A Hybrid III 50th percentile male dummy with targets on the forehead, sternum and superior deltoid region was filmed and high speed videographed in the frontal view. Side view targets were placed on the Hybrid III temporal region, neck and lateral deltoid region. Three 500 frames per second film cameras and two high speed video cameras, operating a 1000 frames per second, were mounted with views both laterally and from the front to observe the dummy and belt restraint component kinematics.

The Hybrid III dummy was positioned in the seat and restraint system as in FMVSS 208 tests, with the back being rocked into place against the seat back and the head leveled. Front view cameras were positioned at the head target height to minimize a foreshortened view of the target motion, however, the data presented has not been corrected for dummy longitudinal motion, such as head nod or leaning forward in the shoulder belt restraint while being pitched from the seat during the roll test. Similarly, side views, capturing the dummy's longitudinal motion were not corrected for lateral motion. Belt tension was measured in the shoulder and lap portions of the belt restraint with load cells placed above the clavicle and outboard of the femur, respectively. The dummy had three load bolt load cells, placed along the anterior aspects of each ilium to help determine pelvic loads due to belt restraint. Tri-axial accelerometers were used in the head, chest and pelvis, and a lumbar load cell measured loads and moments at the base of the lumbar spine. This data is presented in Table 1.

RESULTS:

Data is shown in figures 7 - 14, with average vertical and horizontal displacement shown in parenthesis.

The vertical and horizontal motion of the dummy's head target for the unrestrained dummy is shown in Figure 7. The square wave end point indicates that the dummy had impacted the outer perimeter of the test fixture and was subsequently restrained by the lateral restraint. (note neck loads on unrestrained tests)

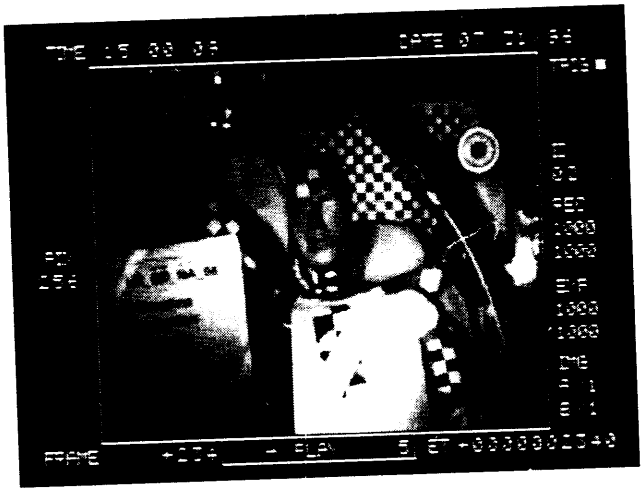
Figure 8 shows the data for the baseline conventional seat and dual retractor stitched latch plate belt restraint. The baseline restraint prevented the dummy from exiting the fixture, but allowed enough vertical (98mm) and lateral (432mm) displacement of the head target to potentially cause partial ejection of the head.

By adding a pretensioner, the vertical displacement was reduced 41 percent while the lateral displacement was reduced by 15 percent (see Figure 9.) The pretensioner removed sufficient slack from the belt restraint system to effectively limit vertical head displacement compared with the baseline system.

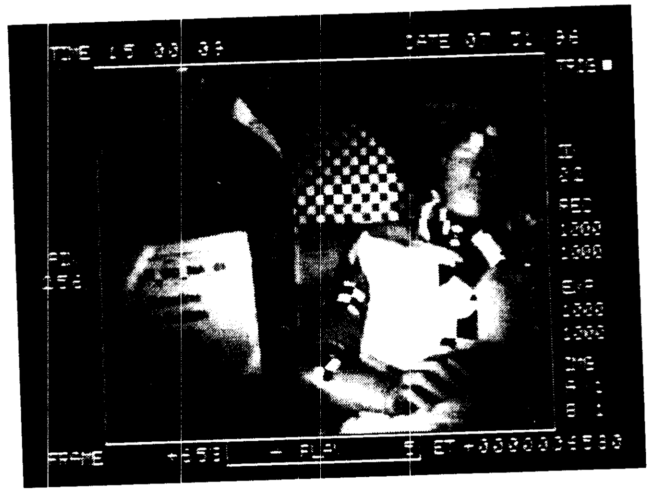
Replacing the dual loop system with a single loop restraint with a free sliding latch plate, and by migrating the outboard anchor point to the outboard seat adjuster, vertical head displacement was also reduced. (see Figure 10.) This reduction of 30 percent relative to the baseline restraint was 11 percent less effective than the baseline system with a pretensioner. The single loop restraint geometry appeared to minimally improve lateral head displacement by an additional four percent when compared to the baseline restraint.

By adding a pretensioner to the single loop restraint system, a reduction of 50 percent, vertical, and 38 percent, lateral head displacement was achieved compared to the baseline restraint system. This is shown in Figure 11

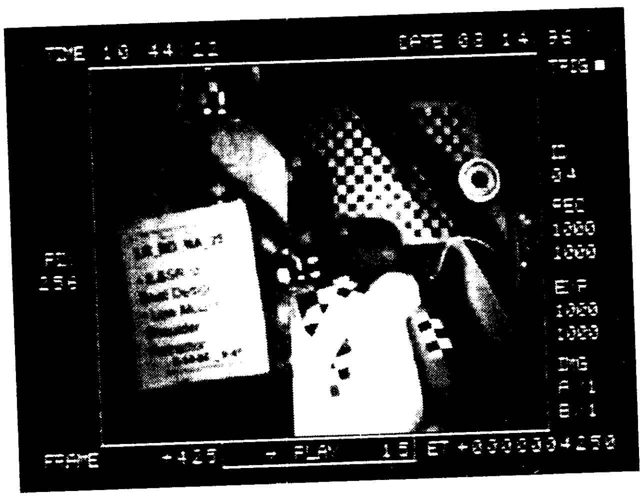
Figure 12 shows results for an IL&SRTS system, consisting of dual retractors, a low mounted shoulder belt retractor on the seat back,



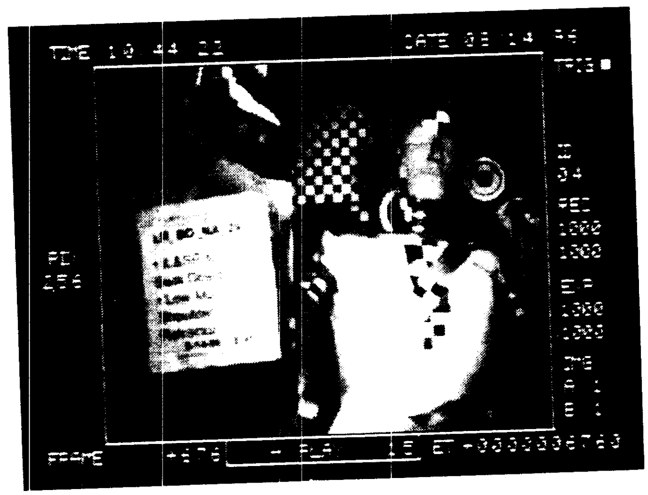
PICTURE 2: START OF TEST - BASELINE RESTRAINT



PICTURE 3: PEAK VERTICAL DISPLACEMENT - BASELINE



PICTURE 4: START OF TEST - IL&SRTS



PICTURE 5: PEAK VERTICAL DISPLACEMENT - IL&SRTS

The dummy rolled further inboard in the Integrated Lap & Shoulder Restraint to Seats (IL&SRTS) when compared with the tests in conventional seats. During the 25 degree from horizontal positioning of the test cage, both IL&SRTS systems allowed approximately 80-120mm of inboard displacement of the dummy's head, as compared to the 50-70mm seen in the conventional seating. While the reasons for this difference are not known, it may be because of different seat back contours or additional belt tension in the longer conventional restraint system's belt routing. The IL&SRTS therefore, has an additional 30-50mm bias included in the lateral displacement data (see pictures 2, 4)

Vertical and lateral tethers were used to prevent the dummy from leaving the boundaries of the fixture, but did not interfere or further restrain the dummy compared to the restraints being tested. The vehicle environment that was simulated consisted of the seat, belt anchorage locations and the belt restraint. The simulated vehicle environment met all vehicle packaging requirements of SAE J1100 and belt location and construction requirements of SAE J383, J384 and J385.

The seats were changed after several tests to insure minimal seat cushion displacement set effects. The specific seat design used had a provision for a headrest mounted belt guideloop, however it was not applied during these tests

Belt restraint systems were changed after each test to eliminate belt elongation effects. Several tests (12,14,15) were conducted to determine the effects of pre-tested restraints. The results appear minimal as shown in data from tests 12,14 and 15.

For optimal test observation, the doors, console, roof, instrument panel, and steering wheel were not simulated.

The simulated vehicle 'B' pillar / rocker interface was the mounting location of the baseline and modified shoulder retractor systems. An adjustable 'D' ring, mounted on the 'B' pillar was positioned in the nominal mid-height position. The non-structural intermediary belt routing guide, normally mounted on the 'B' pillar between the retractor and the 'D' ring was removed to minimize belt slack.

Preliminary tests were conducted to determine if intentional belt slack would affect the results. After reviewing these tests, only tests without intentional slack are reported here. Other tests with live emergency locking retractors (ELR) showed that although the ELR's locked in each test, they contributed to a varying degree of webbing spool out, and hence test variability. The variability appeared to be because of both rotation of the retractor spool and